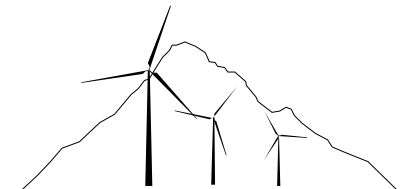


# Estimation of Blade Design Loads

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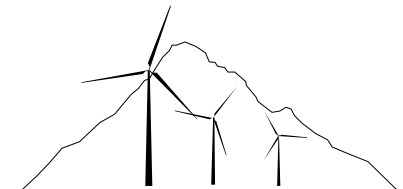
- *Types of loads*
- *Design standards*
- *Testing and Modeling*
- *Sample results*
- *Summary*
- *Discussion*



WINDWARD ENGINEERING

# What Blade Loads are Needed?

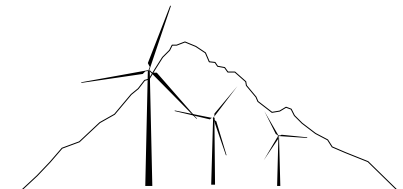
- **Design loads for**
  - Fatigue strength
  - Ultimate strength
  - Maximum out-of-plane deflections (ensure tower clearance)
- **Load components (at multiple spanwise stations)**
  - Flap moments
  - Edge moments
  - Torsion generally less important except for some new blade concepts
  - Spanwise tension (pullout) important to some small turbines
  - Becoming more common to analyze combined load effects (load roses)



# Safety Standards and Design Guidelines

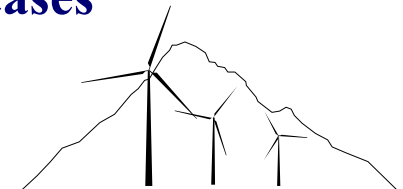
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- **IEC ( International Electrotechnical Commission)**
  - IEC 61400-1 for large turbines
  - IEC 61400-2 for small turbines ( $< 200\text{m}^2$  rotor area)
- **GL (Germanischer-Lloyd)**
  - Efforts underway to harmonize the IEC and GL requirements
- **NREL has developed a set of design guidelines to assist application and interpretation of the IEC standards**
  - Contact Sandy Butterfield at NREL
- **U.S. Technical Advisory Group oversees development of international consensus standards**
  - Contact Craig Hansen for more information



# Load Cases

- **Wind conditions**
  - Turbulence
  - Discrete gusts (1- and 50-yr recurrence interval)
  - Other (temperature, ice, lightning, grid status, etc.)
- **Turbine Status**
  - Normal power production
  - Power production with a fault
  - Normal parked rotor in 50-yr extreme winds (may include grid loss)
  - Parked rotor with single fault in 1-yr extreme winds
- **Standards specify numerous load cases as the minimum set that must be run**
  - Seek worst-case loads and fatigue loads among all cases



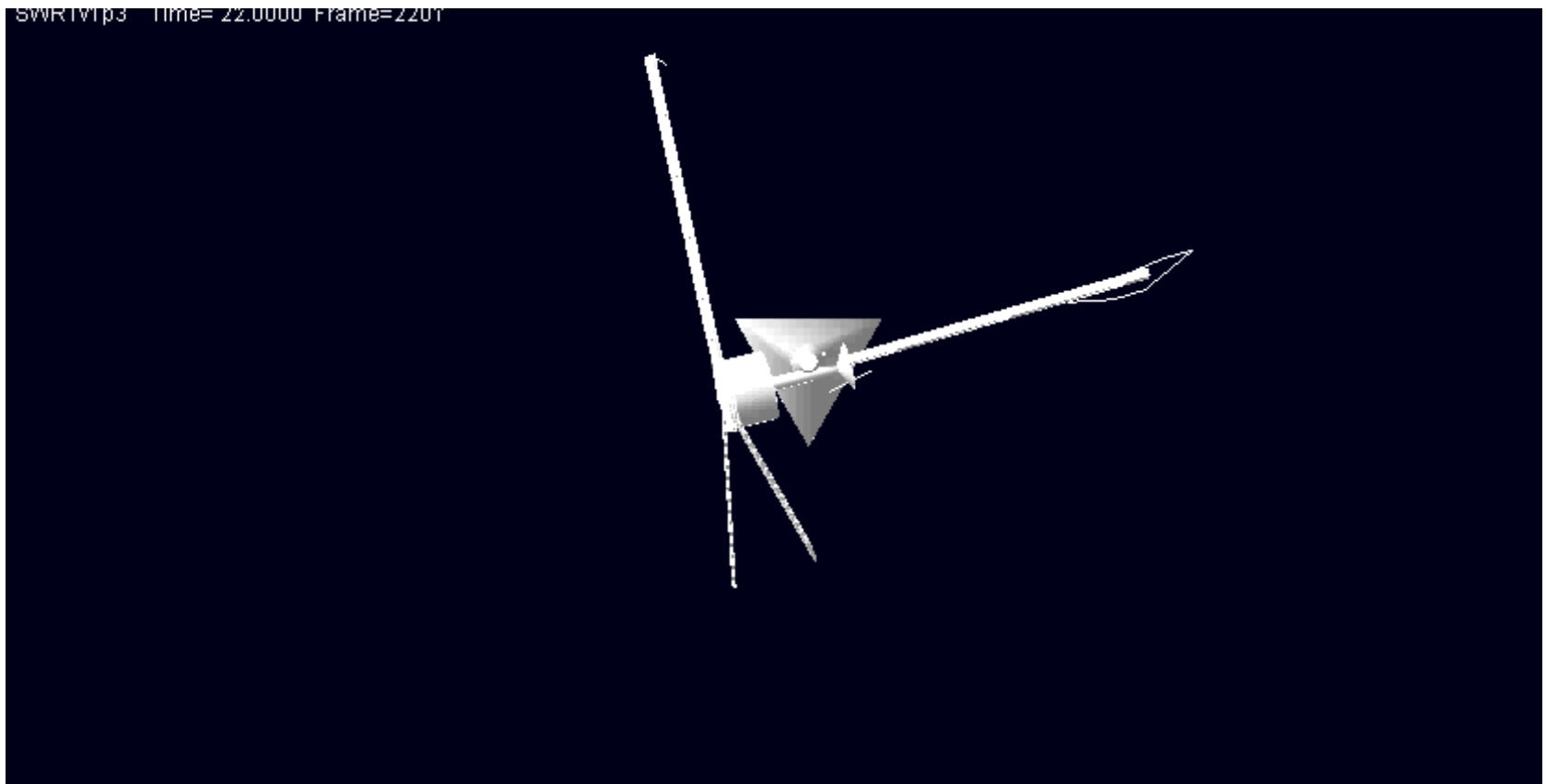
# Estimating Design Loads

- **Testing alone is not a viable option**
  - Impossible to test in all extreme conditions required by the standards
- **Computer modeling is required**
  - Model must be validated with test data
  - Model is then used to simulate all load cases and extract fatigue and extreme load values
- **Models must include**
  - Aerodynamics (unsteady wake effects, static stall, dynamic stall, etc.)
  - Structural dynamics (and aeroelastic interaction with aerodynamic forces)
  - Control systems
  - Fault conditions
- **Codes commonly used in the U.S.**
  - Fast (available at no cost from NREL, best choice for “typical” configurations)
  - ADAMS® (unlimited capability for turbine configurations, but license fees and steep learning curve)



# ADAMS® Animation

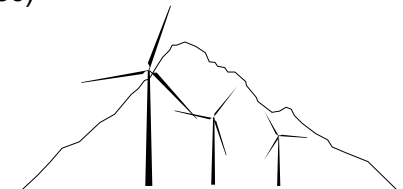
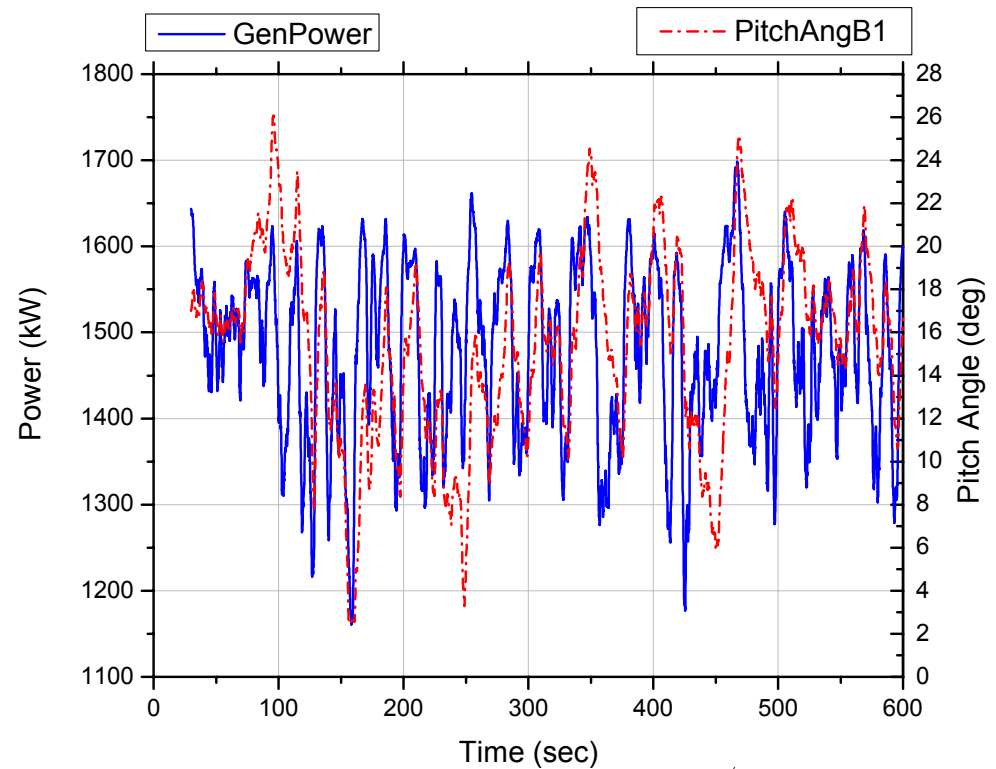
- NREL Small Wind Research Turbine (modified Bergey 10kW furling system)
- IEC ECD gust (speed increase from 12 to 27 m/s while direction shifts 60°)



# Sample Results—ADAMS Predictions

- WindPACT Rotor Study  
“Baseline” Rotor
  - NREL sponsored project to explore a wide variety of rotor concepts
  - 1.5MW rating
  - Variable speed generator
  - Full-span pitch control (3 blades coupled)
- Two examples
  - Normal operation in 16 m/s turbulence
  - Parked rotor in 42.5 m/s turbulence

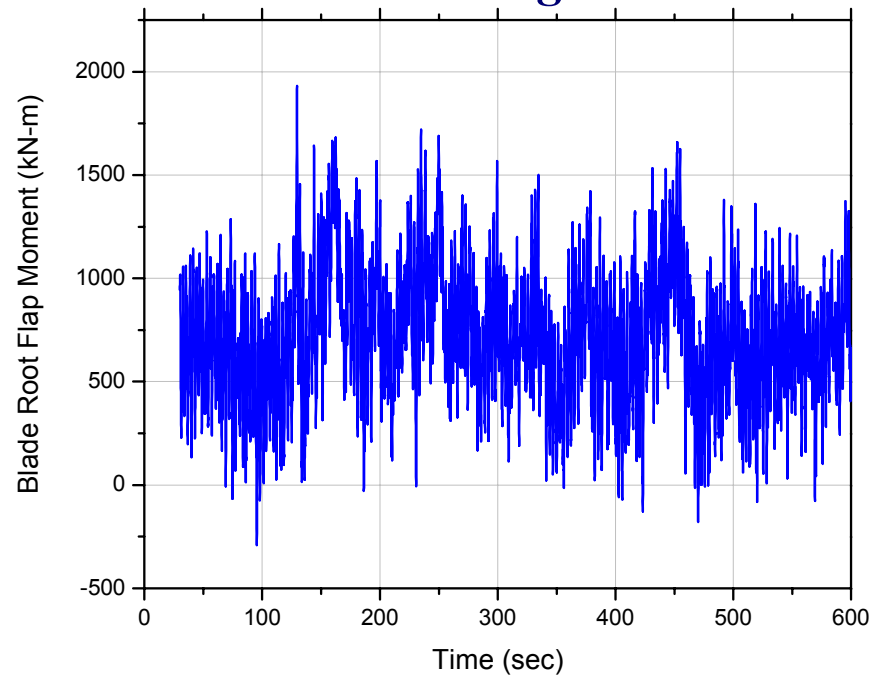
*Normal operation in 16 m/s  
turbulence*



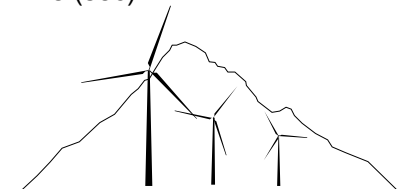
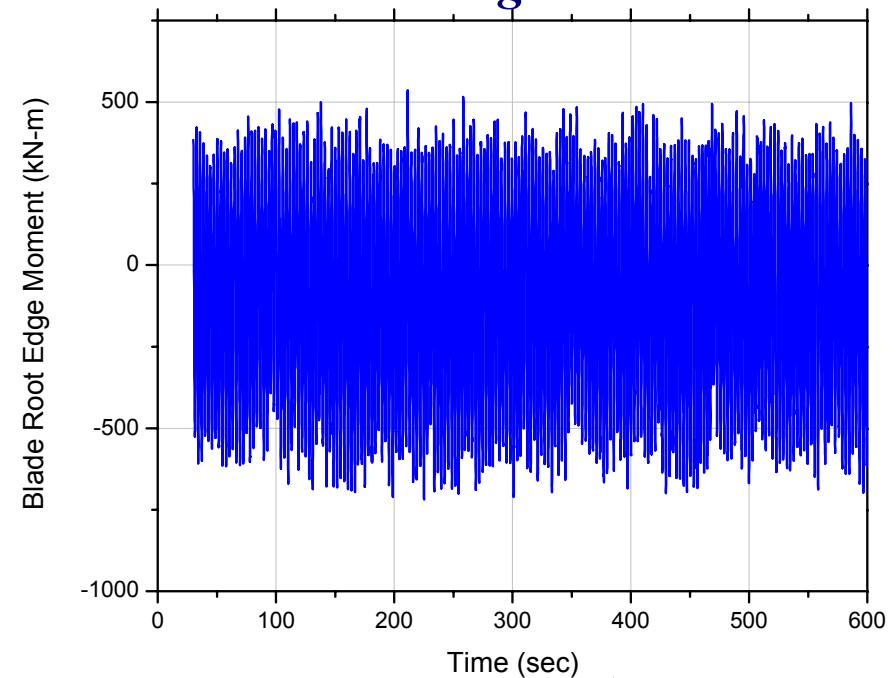
# Sample Results—Blade Root Loads

- Normal operation in 16 m/s turbulence

*Flap loads dominated by wind loading*



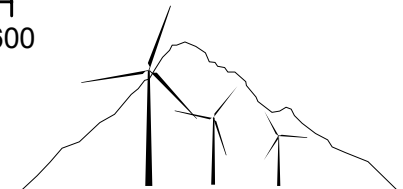
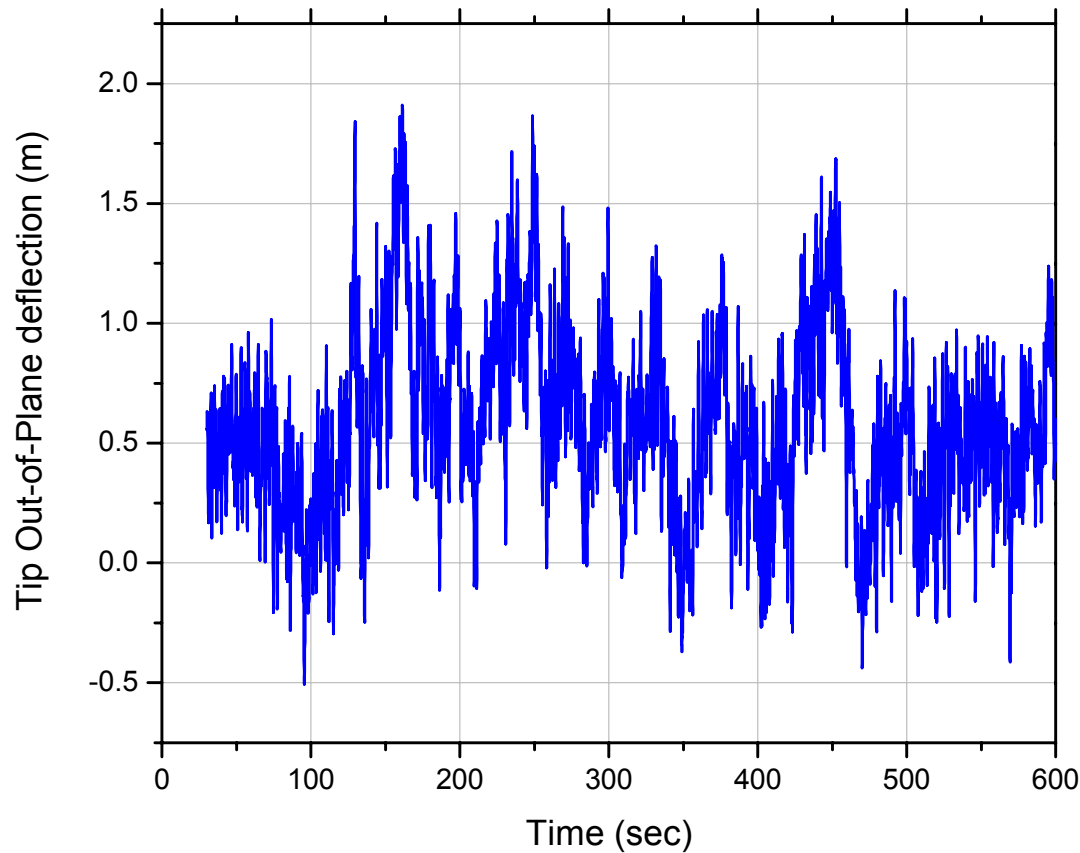
*Edge loads dominated by blade weight*





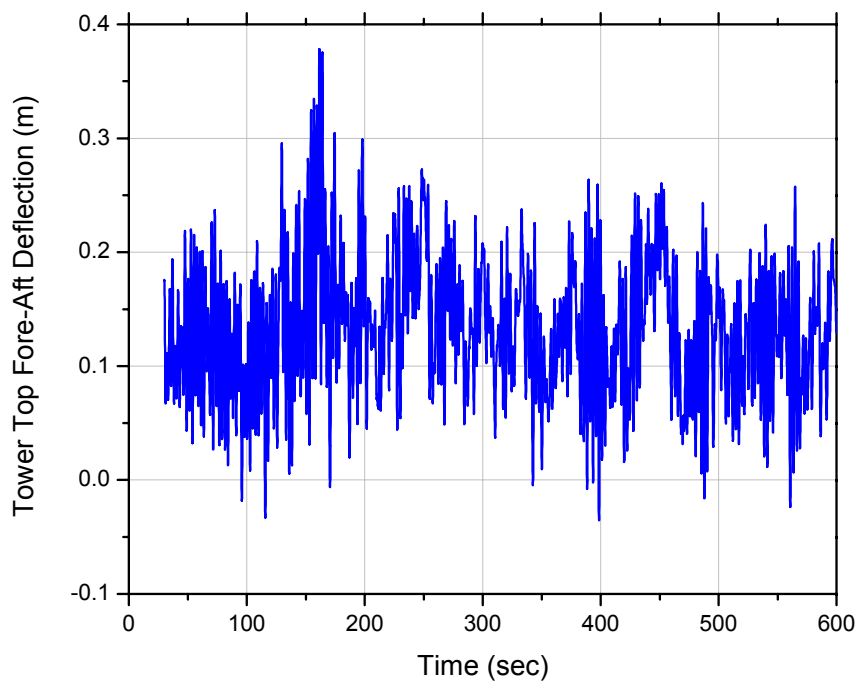
# Sample Results—Blade Tip Deflection

- Normal operation in 16 m/s turbulence

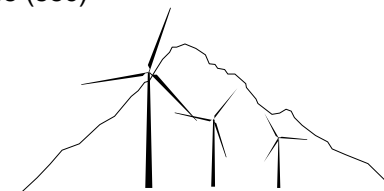
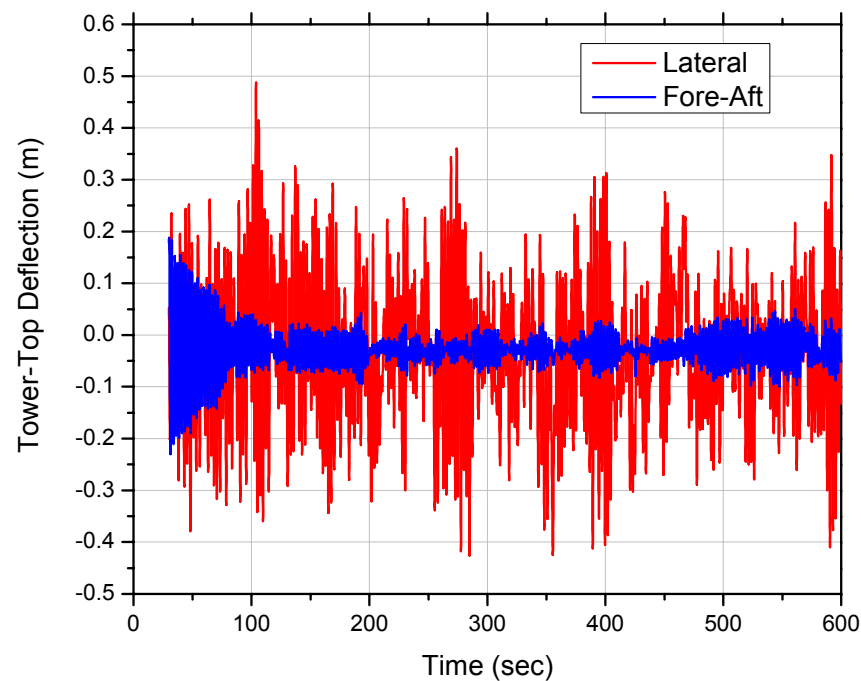


# Sample Results—Tower Deflections

*Normal operation in 16 m/s  
turbulence*



*Parked rotor in 42.5 m/s  
turbulence*



# Summary

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- **Simulations must be used to estimate design loads**
  - Models validated with test data
- **Hundreds of simulations are required to meet current IEC and GL standards**
  - Normal operation, control actions, parked rotor, faults
- **Fatigue and peak loads, and peak deflections are extracted from all simulations**
  - Rainflow cycle counting is generally used to estimate fatigue damage
  - Combined load effects should be considered in many situations

